A Survey on Satellite and Ground Integrated Network Systems

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***Abstract*—Low-earth orbit (LEO) satellite networks enable communication services in areas beyond the coverage of terrestrial base stations. This system is considered a key technology for 6G communications as it offers lower latency and less signal attenuation compared to geostationary satellites, achieving high throughput. By integrating these satellite networks with terrestrial base stations, a network structure can be created that combines the wide coverage of satellites with the data processing capabilities of terrestrial base stations, providing a more reliable and flexible communication environment. Therefore, to address the increasing number of connected devices and the rise in network density due to the growth of IoT, recent research on integrated satellite-terrestrial network systems is actively being conducted. In this paper, we investigate the latest research topics, such as space-air-ground integrated networks (SAGIN), RIS-integrated systems, security issues, and semantic-aware SAGIN systems.**

***Index Terms*—space-air-ground integrated networks, sematic-aware control, 6G networks, machine learning.**

I. INTRODUCTION

A satellite network is a communication system that uses satellites to achieve global coverage, playing a crucial role in areas beyond the coverage of terrestrial base stations. Satellite networks can be classified in various ways depending on the orbit of the satellites and can be divided into Low earth orbit (LEO) satellite networks and Geostationary earth orbit (GEO) satellite networks. LEO satellite networks consist of satellites deployed at low altitudes, approximately 500 km to 1,000 km above the Earth's surface, providing low latency and high data transfer speeds. However, since a single satellite cannot continuously service a specific area, a constellation of satellites is essential. Representative examples include Starlink and OneWeb. GEO satellite networks consist of satellites that rotate at the same speed as the Earth at an altitude of about 35,786 km above the Earth's equator. They can provide continuous service to a single point, achieving global coverage with a relatively small number of satellites. However, due to the long distance from Earth, there are issues with long signal latency and significant signal attenuation, leading to high costs for providing real-time services [1].

The integrated system of satellite networks and terrestrial base stations is gaining attention as next-generation technology for global services [2]. Combining the performance of terrestrial networks with the extensive coverage of satellite communications enables fast and reliable service even in geographically isolated areas. This integrated network includes backhaul connections to facilitate smooth cooperation between satellites and terrestrial base stations, serving to send data transmitted via satellites to terrestrial base stations. Additionally, through a hybrid connection method, automatic switching between satellites and terrestrial base stations occurs based on user location or network conditions. However, in integrated networks, different latencies between terrestrial base stations and geostationary satellites and the Doppler effect due to the movement of LEO satellites pose challenges for maintaining stable connections. Thus, this paper investigates recent research trends in satellite-terrestrial integrated networks.

II. SPACE-AIR-GROUND INTEGRATED NETWORK

Although 5G networks are currently being deployed globally, there are still several limitations regarding coverage, location tracking accuracy, and communication performance. To address these limitations, 6G networks are designed to provide global coverage and higher location tracking precision. In particular, with the advancement of Internet of Things (IoT) technology, the demand for systems that integrate communications, location tracking, and detection is growing. However, terrestrial networks have coverage limitations in areas with insufficient infrastructure or where obstacles block signals. Therefore, [3] proposes a system integrating massive MIMO networks with low Earth orbit (LEO) satellite systems to improve communication efficiency and location tracking accuracy simultaneously. In this context, they derive a lower bound on channel capacity based on statistical channel state information, considering the Doppler effect caused by satellite movement and inaccuracies in channel state information due to signal delay. They propose a joint optimization technique considering the trade-off between throughput and location tracking.

A satellite-RIS integrated system applying Reconfigurable Intelligent Surface (RIS) technology is proposed in [4] to address the issue of degraded communication performance in urban environments where buildings block terrestrial base station signals. RIS technology can improve communication performance by appropriately controlling the phase of impinging signals. When satellite signals are blocked by obstacles, this technology enables stable communication by reconstructing the signals. A beamforming and RIS phase control algorithm is proposed that minimizes power consumption between satellites and BS while satisfying user QoS.

Additionally, to support the increasing communication demand of IoT devices, [5] proposes an interference management and spectral efficiency maximization technique using rate-splitting multiple access (RSMA) technologies in satellite and aerial integrated networks. RSMA divides transmission signals into common and private streams, suppressing interference and improving spectrum efficiency, which allows for control of user interference in UAV networks. They propose an SCA-based optimization algorithm to maximize spectrum efficiency in such systems, with experimental results showing that the proposed technique effectively eliminates interference and enhances system throughput compared to existing methods.

With the exponential increase in IoT devices, the number of communication devices subject to eavesdropping is also increasing exponentially. These devices have limitations in computational capability and power constraints, making it difficult to apply end-to-end encryption technologies. Additionally, long-distance transmissions by satellites are prone to eavesdropping and pose security vulnerabilities. Therefore, [6] proposes a technology that weakens signals received by eavesdroppers at the physical layer according to channel conditions. Using an SCA method, they address the security-energy efficiency (SEE) maximization problem through hybrid beamforming at satellites and base stations. Particularly in multi-beam satellite systems, they enhance security performance while suppressing interference between satellites and ground stations by considering imperfect channel state information.

Also, [7] introduces an activity-network-things (ANT) centric security reference architecture to address cybersecurity challenges in SAGIN-enabled IoT systems. Motivated by the need for secure anywhere connectivity in smart cities, it analyzes security requirements through activity-centric, network-centric, and things-centric views. The system model integrates satellite, aerial, and ground networks for real-time vehicular communication. The proposed algorithm identifies critical activities and applies security controls using microperimeters around sensitive areas. This ensures secure data transmission across heterogeneous networks while maintaining low latency. The architecture is flexible enough to be applied beyond vehicular systems to other smart city applications.

III. SEMANTIC AWARE SAGIN

Space-air-ground integrated networks (SAGIN) aim to provide seamless data connectivity across diverse platforms, including satellites, high-altitude platforms, unmanned aerial vehicles, and ground vehicles. As these platforms evolve with advancements in sensing, computing, communication, and intelligence, traditional communication systems are transforming into intelligent agents capable of facilitating task-driven functional networking. To address the complexities of managing such heterogeneous networks, a task-driven multi-agent intelligent networking (MAIN) architecture is proposed in [8]. MAIN leverages semantic intelligence powered by large language models to enhance sensing, decision-making, control, and communication functions. This architecture integrates mission intent, communication, and physical entity domains through an intent-driven management and control mechanism, optimizing the orchestration of cross-domain functions and resources for specific tasks. By enabling intelligent agents to execute complex tasks collaboratively, MAIN significantly improves task accomplishment efficiency within SAGIN.

Also, recent advancements in generative AI offer promising solutions to enhance various aspects of SAGIN, including channel modeling, resource allocation, network deployment, semantic communications, image processing, and security [9]. SAGIN can achieve more efficient and adaptive network management by leveraging generative models such as generative adversarial network, variational autoencoder, generative diffusion model (GDM), and transformer. The proposed integration framework utilizes generative AI in the cloud to handle intensive computations, enabling centralized processing and strategy generation for distributed SAGIN components like satellites, UAVs, and ground transmitters. A case study demonstrates the use of GDM to construct channel information maps, significantly enhancing the quality of service by improving channel estimation and reducing energy consumption. Additionally, generative AI facilitates intelligent resource allocation by dynamically optimizing UAV trajectories and transmit power based on real-time network conditions.

CONCLUSION

This paper investigates the latest research topics in realizing integrated satellite and terrestrial networks, focusing on communication and sensing integration systems, satellite-RIS integration systems, satellite-UAV integration systems, and the security issues associated with these systems. Semantic-aware network control systems have also been investigated, focusing on optimizing communication efficiency by understanding and utilizing the semantic meaning of transmitted data.

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